High-Intensity Heavy Ion Accelerator Facility (HIAF)

Status and challenges of HIAF project in China

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MOPM2P90

July 04th, 2016, HB2016

Outline

1. **Background and HIAF facility overview**
2. **Unique features of HIAF facility**
3. **Technical Challenges and key technology R&D**
4. **Summary**

Background and science motivation

- **HIAF: One of 16 large-scale research facilities proposed in China in order to boost basic science, now under design optimization and technical R&D.**

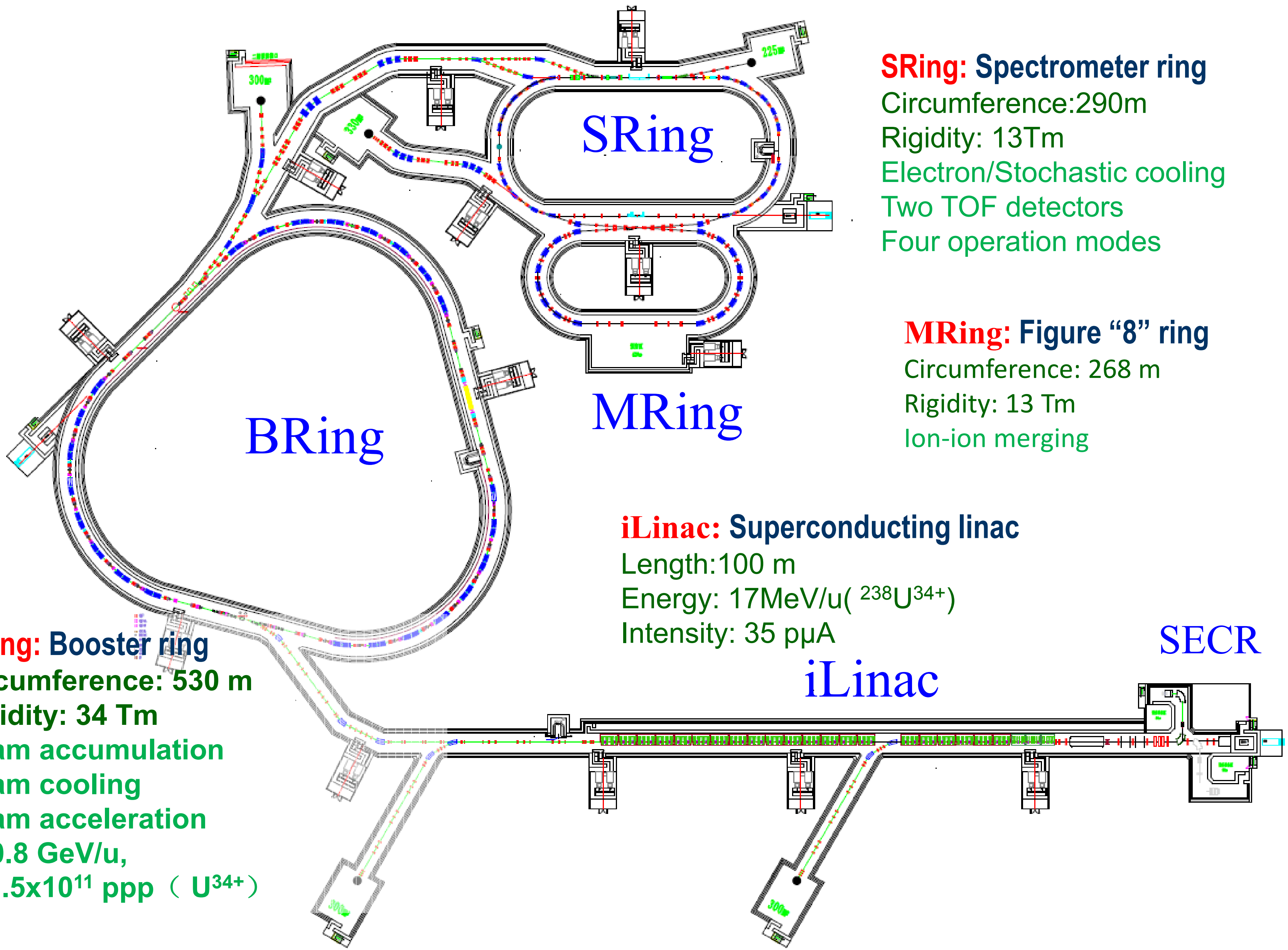
  HIAF phase-I was approved officially in 31, Dec. 2015

Science motivations of HIAF phase-I :

- **Nuclear Physics:** High intensity radioactive beams to investigate the structure of exotic nuclei; Synthesis of new isotopes near the proton-drip line; Structure and reaction mechanism with exotic beams; Precise mass measurements for short-lived nuclei
- **Nuclear astrophysics:** Origin of chemical elements in cosmos; Evolution of stars and energy generation; What are the nuclear reactions that drive stars and stellar explosions?
- **Atomic physics:** Highly-charged atomic physics, such as, precision laser spectroscopy of highly charged ions, dielectric recombination spectroscopy, DR spectroscopy of radioactive nuclides, …

  Study a fundamental problem of QED-spontaneous electron-positron pair creation in supercritical Coulomb fields.

HIAF Layout ----Phase I



SRing: Spectrometer ring
Circumference:290m
Rigidity: 13Tm
Electron/Stochastic cooling
Two TOF detectors
Four operation modes

MRing: Figure “8” ring
Circumference: 268 m
Rigidity: 13 Tm
Ion-ion merging

iLinac: Superconducting linac
Length:100 m
Energy: 17MeV/u($^{238}U^{34+}$)
Intensity: 35 pμA

BRing: Booster ring
Circumference: 530 m
Rigidity: 34 Tm
Beam accumulation
Beam cooling
Beam acceleration
E=0.8 GeV/u,
I= 1.5×10^{11} ppp（ U^{34+}）

HIAF Beam Parameters

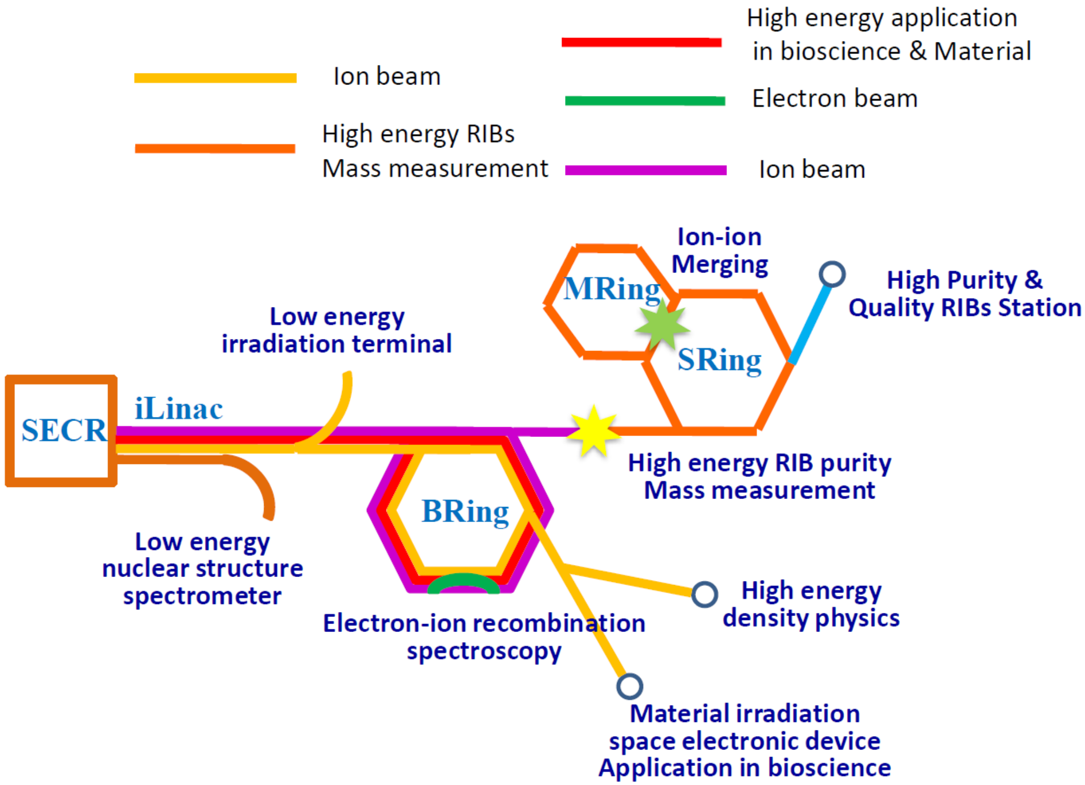
	Typical Ions	Energy	Intensity
SECR	$^{238}U^{34+}$	14 keV/u	50 pμA
iLinac	$^{238}U^{34+}$	17 MeV/u	35 pμA
BRing	$^{238}U^{34+}$	0.8 GeV/u	~1.5×10^{11} ppp
SRing	RIBs: neutron-rich, proton-rich	0.84 GeV/u(A/q=3)	~10$^{9-10}$ ppp
	Fully stripped heavy ions H-like, He-like heavy ions	0.8 GeV/u($^{238}U^{92+}$)	~10$^{11-12}$ ppp
MRing	$^{238}U^{92+}$	0.8 GeV/u	~1.0×10^{11} ppp

HIAF performance and operation modes

- **Higher beam Intensity(Comparison with HIRFL-CSR):**

  - **Primary beam intensity increases by 1000-10000**
  - **secondary beam intensity increases by 10000**

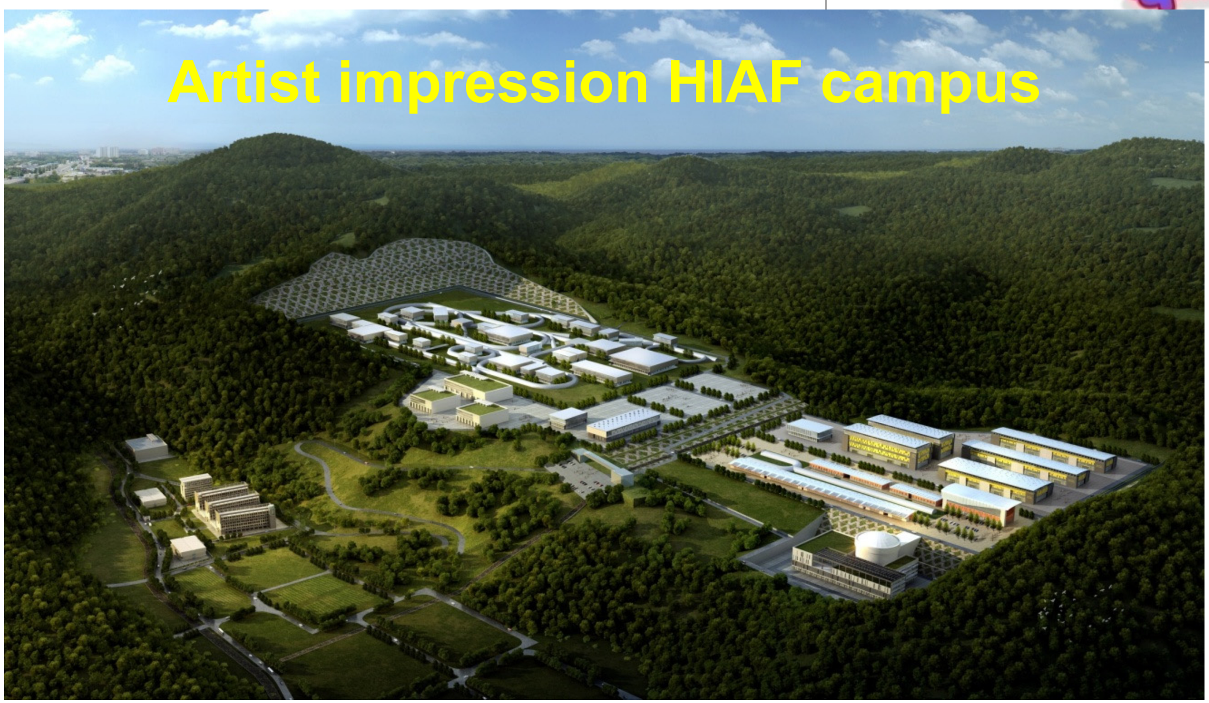
- **Precisely-tailored beams:** beam cooling (*Electron, Stochastic, laser)*
- **Versatile operation modes:** parallel operation, beam splitting



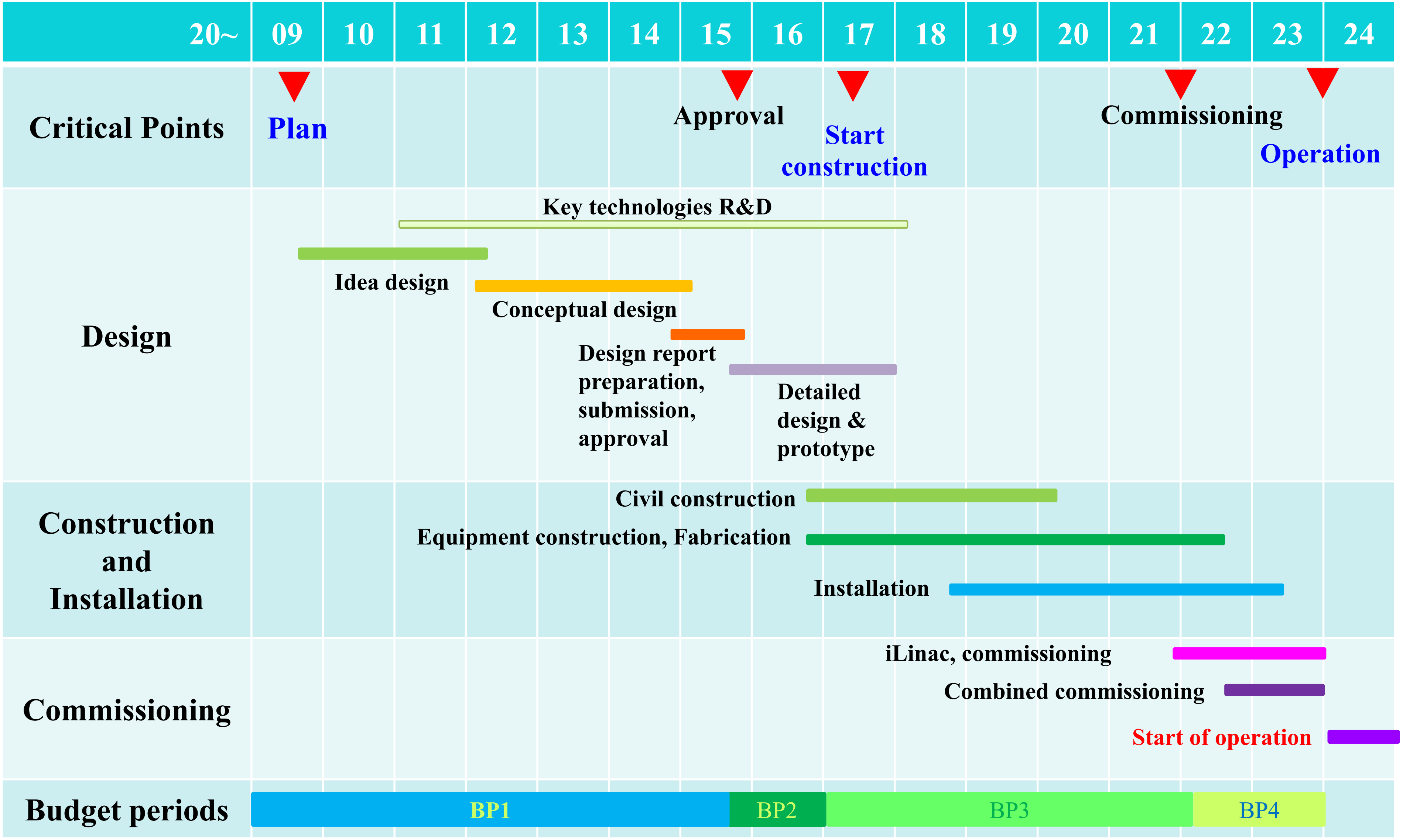
HIAF budget and site

Total Budget : 2.53 B RMB¥.
1.53 B RMB¥, for facility, from central gov.
1.0 B RMB¥, for land & infrastructure, from local

HIAF site



HIAF Schedule



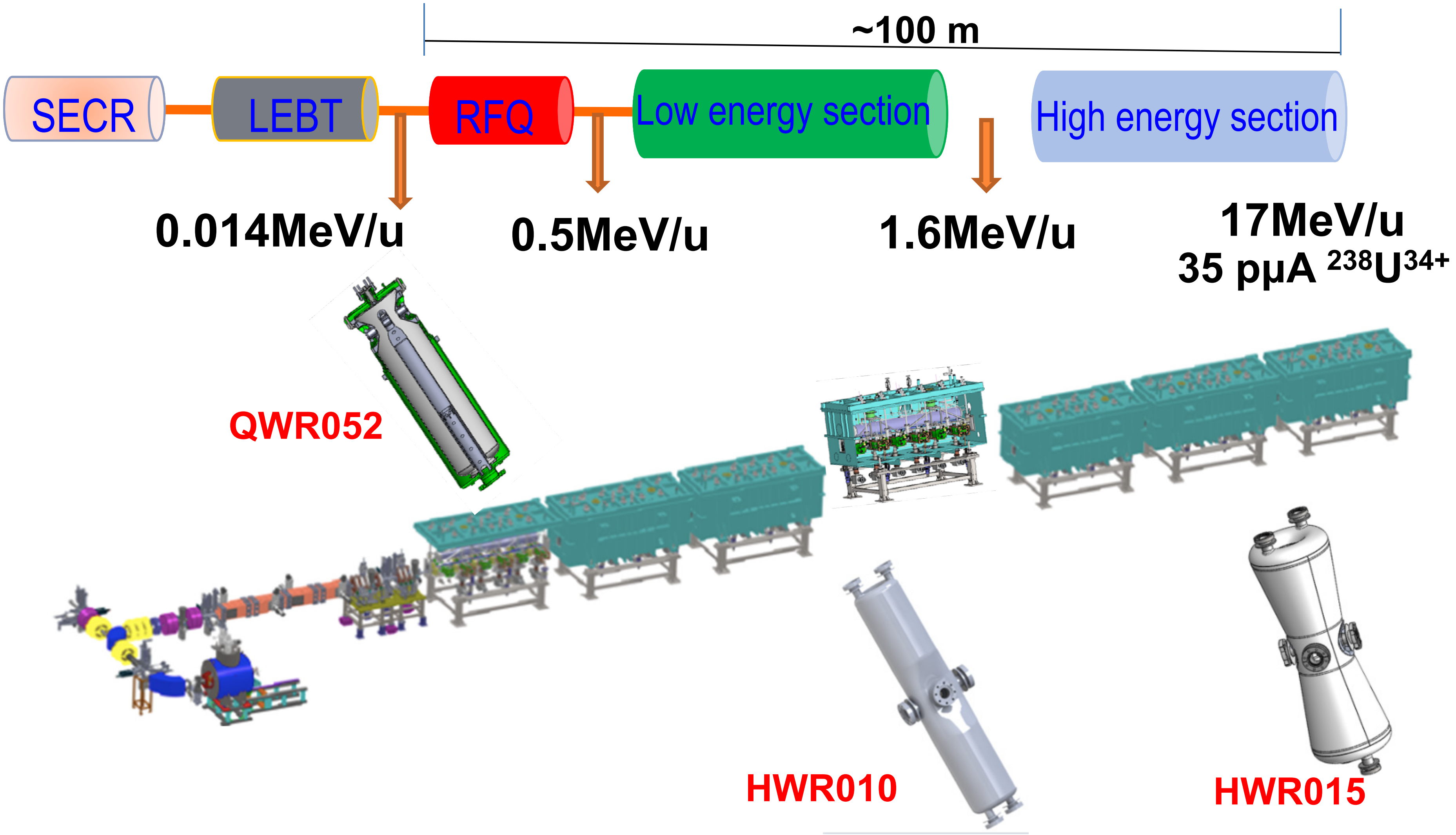
HIAF Unique Features

- **High Intensity superconducting iLinac as a injector**
- **Two-plane painting injection scheme**
- **“Pre+ Ring” radioactive beam line**
- **Figure-8 shape ion-ion merging**
- **Multi-function storage ring（SRing)**

Feature-1

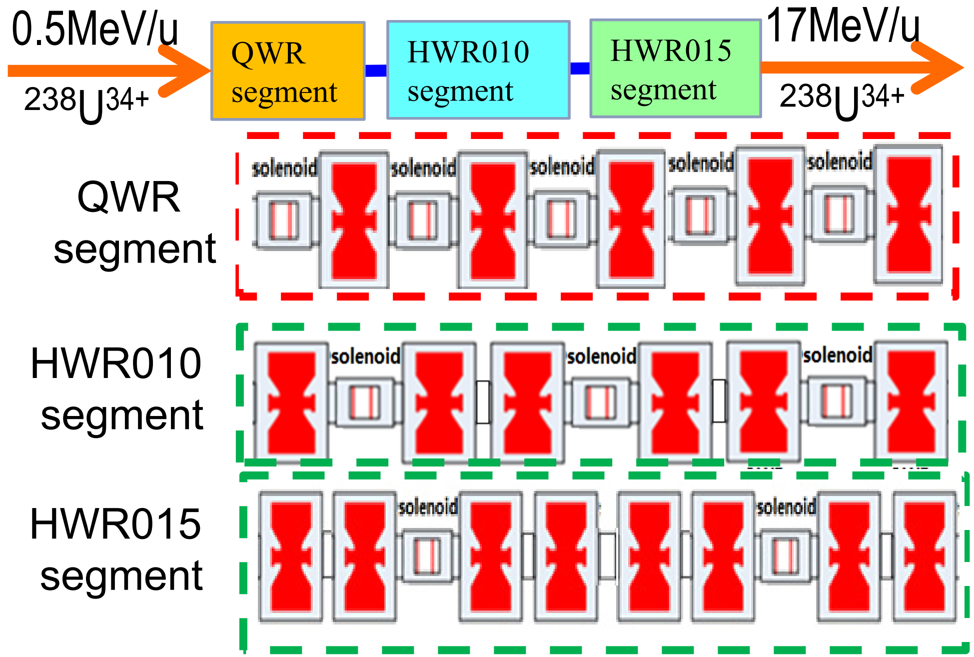
Superconducting iLinac

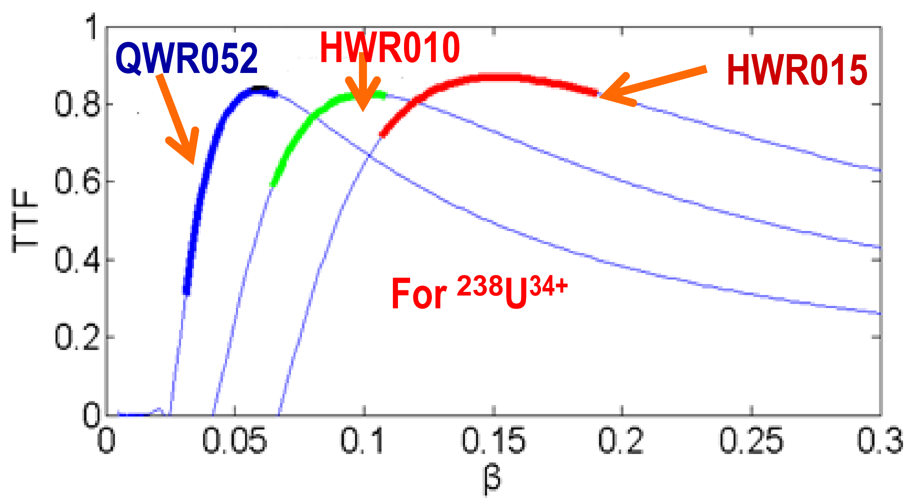
iLinac: **Highest beam intensity of superconducting heavy ion linac in the world**



Superconducting iLinac Lattice Structure

Cavity Type 1	
Cavity type / β	QWR / 0.052
Frequency(MHz)	81.25
NO of cavity	15
Epeak of cavity（MV/m）	25
Bpeak of cavity(mT)	50
Cavity Type 2	
Cavity type / β	HWR / 0.10
Frequency(MHz)	162.5
NO of cavity	36
Epeak of cavity（MV/m）	25
Bpeak of cavity(mT)	50
Cavity Type 3	
Cavity type / β	HWR / 0.15
Frequency(MHz)	162.5
NO of cavity	52
Epeak of cavity（MV/m）	32
Bpeak of cavity(mT)	41.3





Two-plane painting injection

Feature-2

iLinac	BRing	Gain	Scheme
35pμA (U^{34+}) →	**2.0×10^{11}**	**66**	Multi-turn injection + Electron Cooling

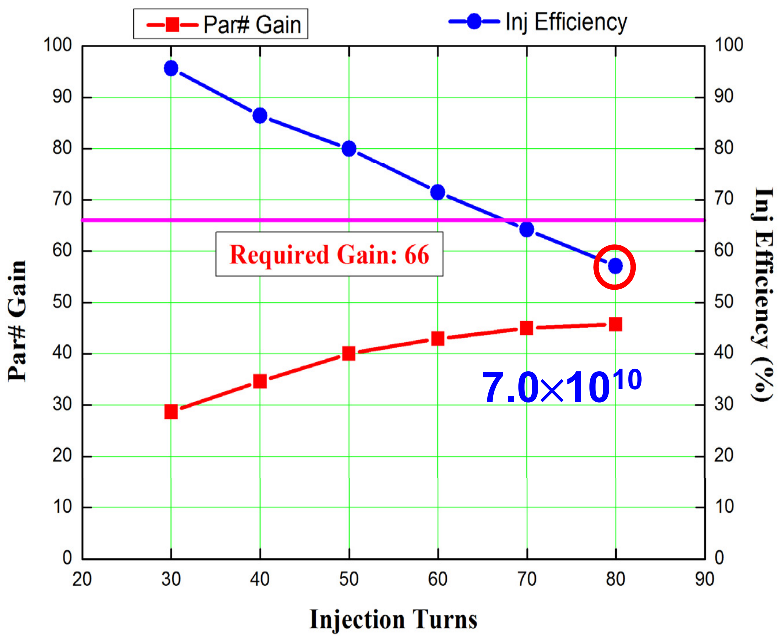
Single Plane: HIAF BRing:

$$N_{inj} \approx \frac{A}{1.5\varepsilon_i} \approx \frac{200\,pimmmrad}{1.5\times 5\,pimmmrad} \approx 26$$

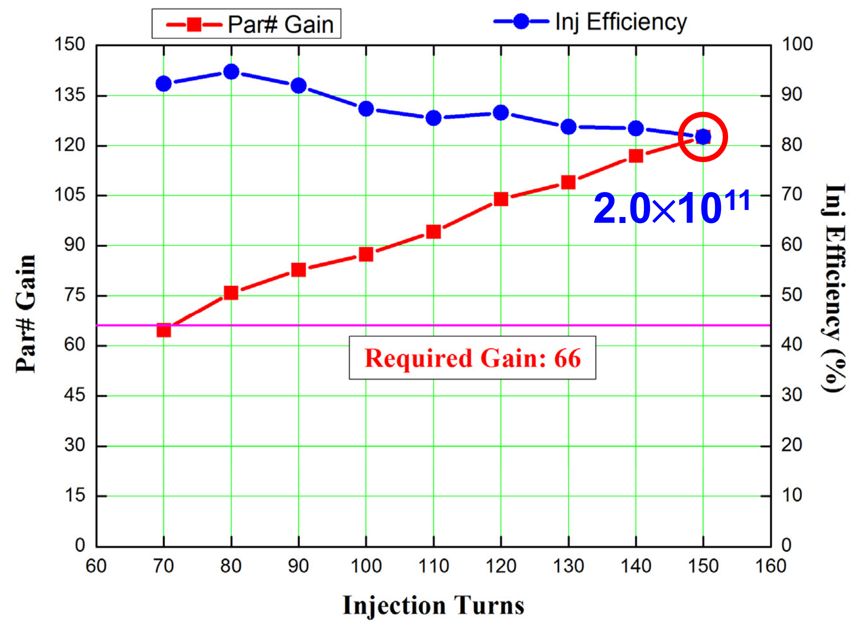
Two planes painting injection supported by electron cooling

Details in Dr. W.P.Chai's presentation: WEAM8X01

Two-plane painting injection



Single-plane injection



Two-plane painting

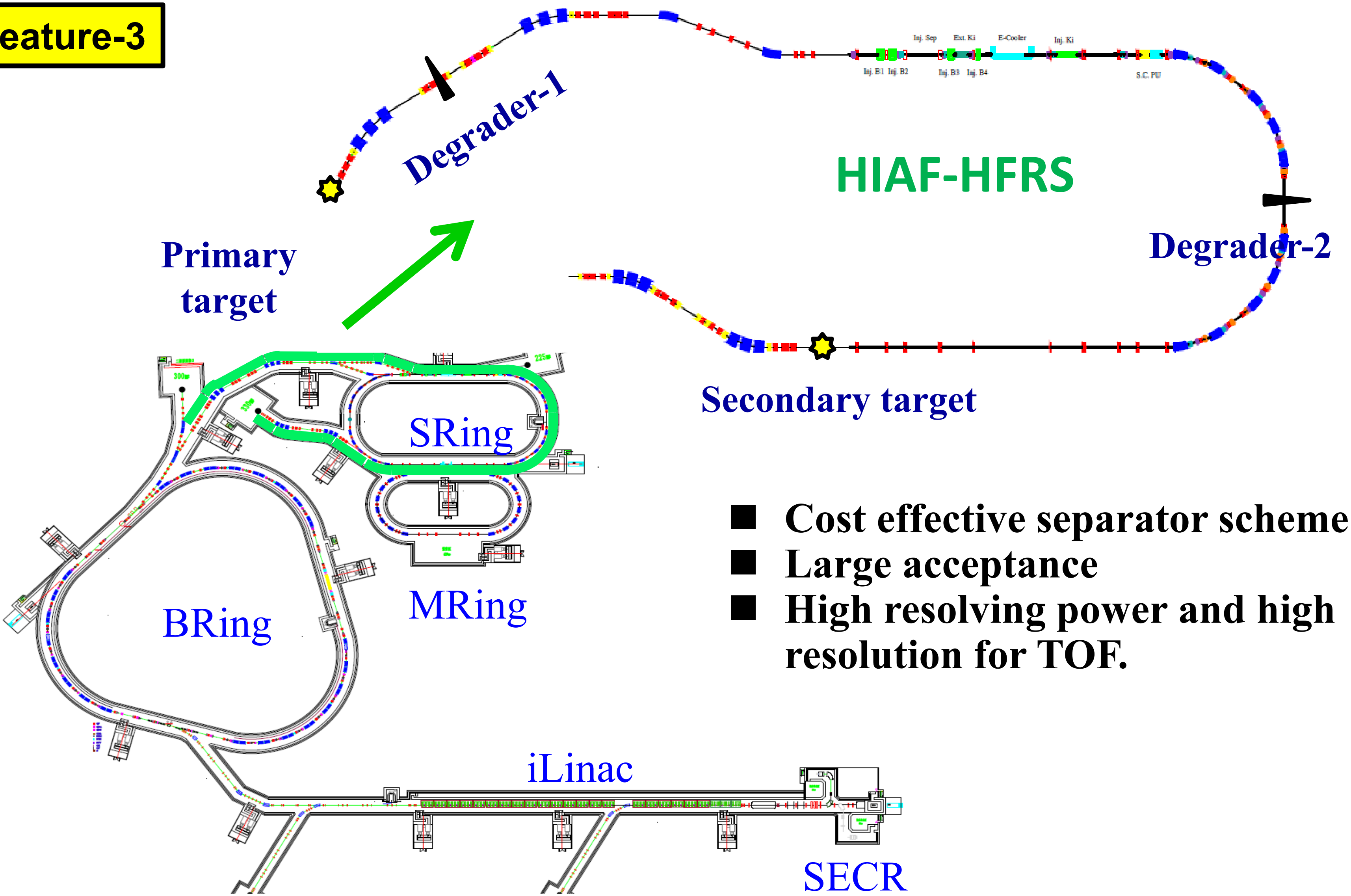
Conclusions:

- The beam intensity could reach 2.0×10^{11} from simulation results, nearly 3 times over the conventional single-plane injection.

- 5 times enhancement factor over single-plane injection can be expected by optimizing the working point.

Details in Dr. W.P.Chai's presentation: WEAM8X01

Feature-3

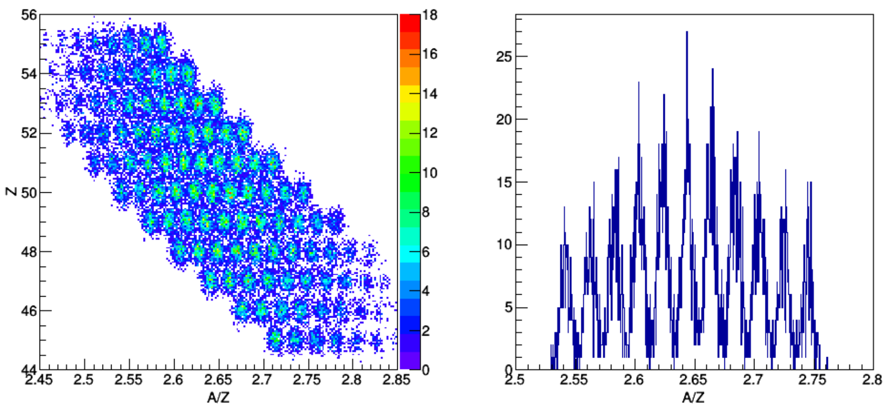


- Cost effective separator scheme
- Large acceptance
- High resolving power and high resolution for TOF.

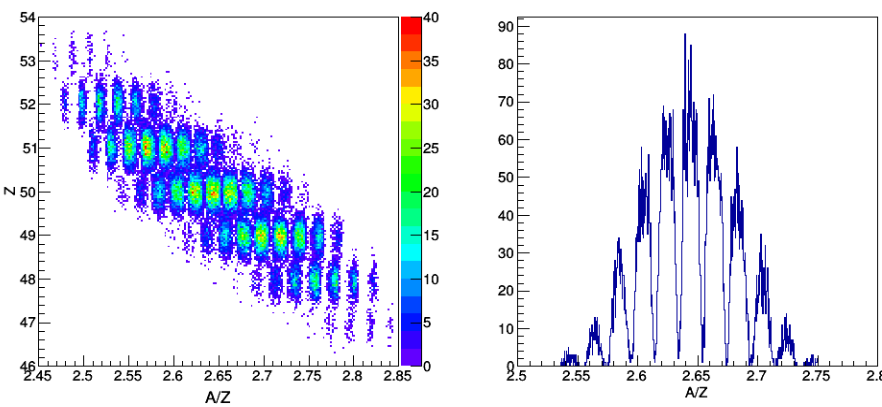
“Pre + Ring” long time of flight separator

- $^{238}U^{34+}$@800MeV/u + ^{208}Pb -> ^{132}Sn
- Bρ+TOF+ΔE

Pre + standard beam line



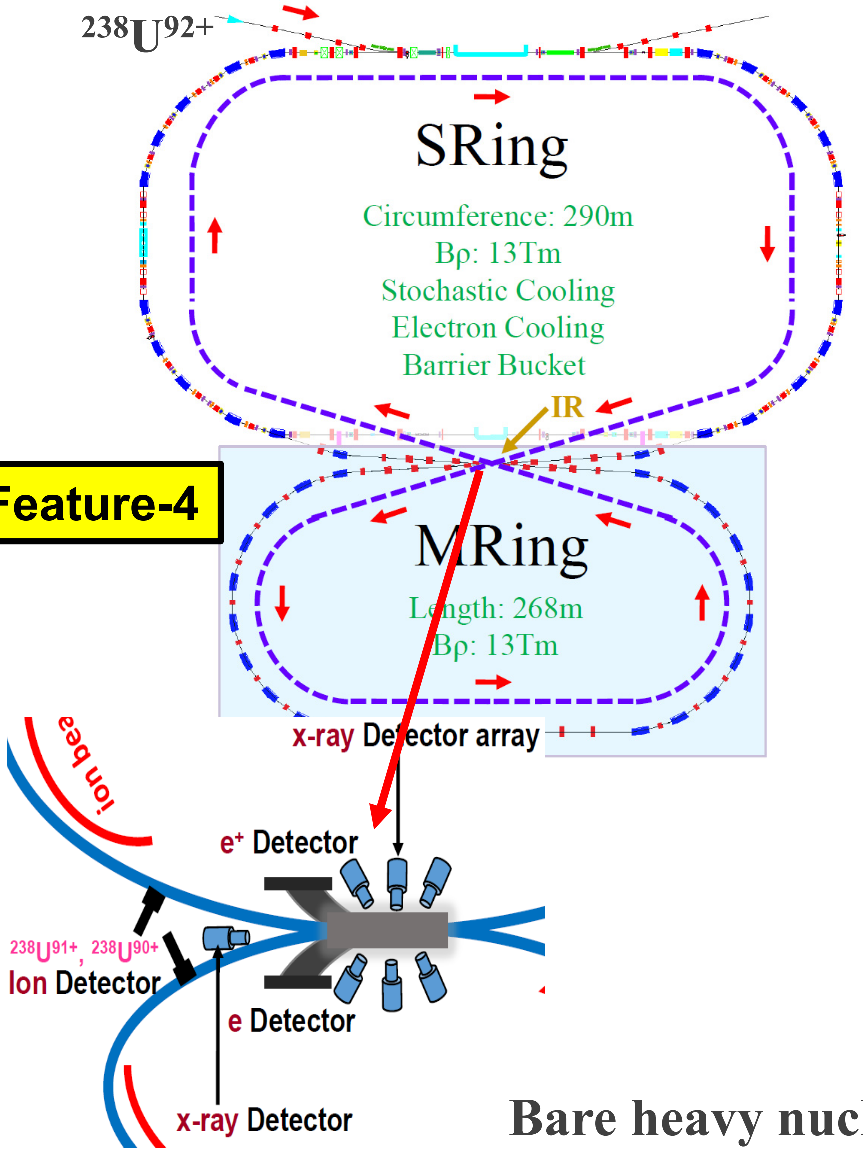
Pre + Ring



The selectivity and resolution for RIB can be improved dramatically with the long time of flight

Figure "8" shape ion-ion merging

Feature-4



First ion-ion merging facility in the world based on storage ring

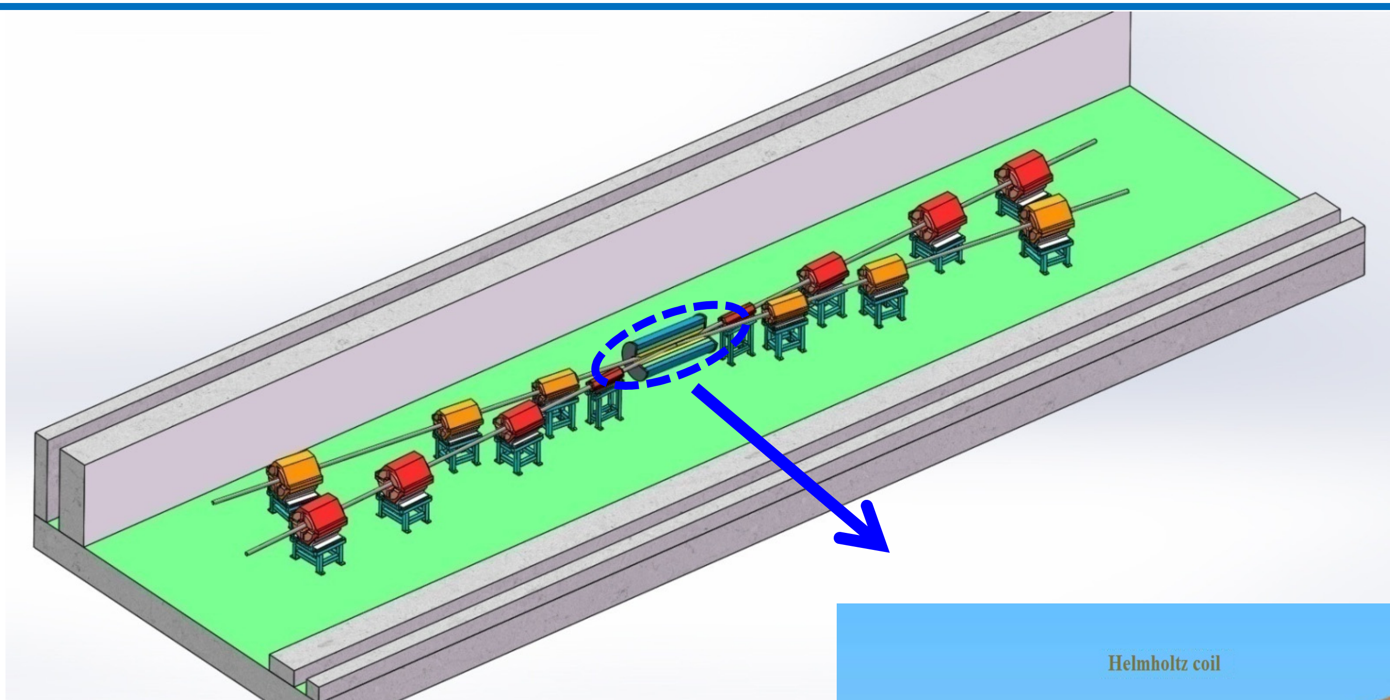
- Sharing the injection and cooling system
- "8" shape storage ring with coasting beam merging with itself scheme
- Barrier Bucket stacking

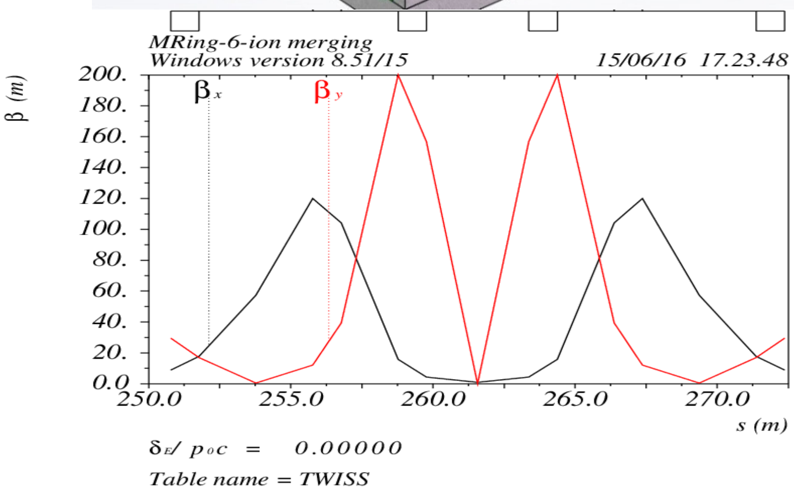
Storage ring QED-spontaneous electron-positron pair production

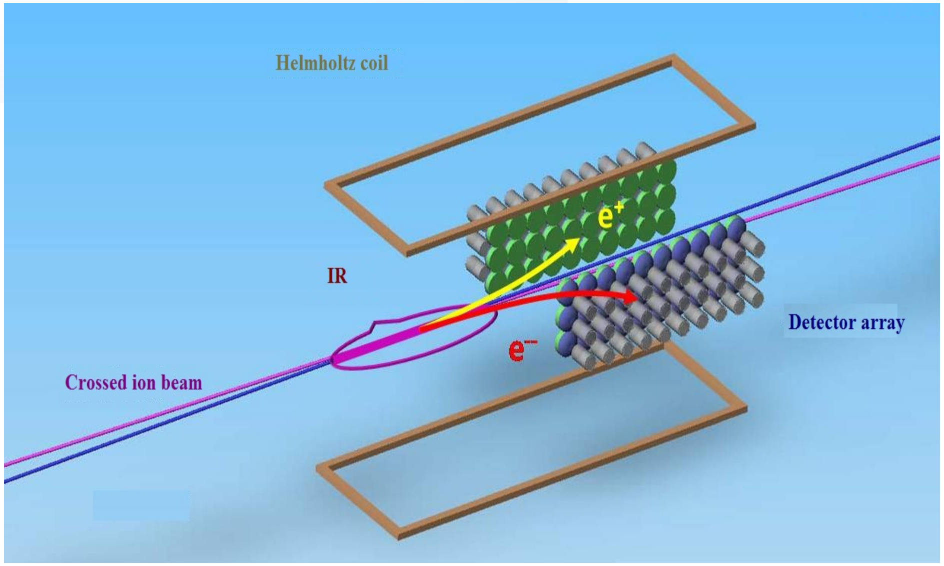
- No electron-electron correlation
- Ultra-low background signals
- Small angle collision provides the CM energy (6~8MeV/u) to cross column barrier
- The production is easy to separate and goes along Z axis

Bare heavy nuclei, e.g. $^{238}U^{92+}$, Z1 + Z2 =184 ≥ 173

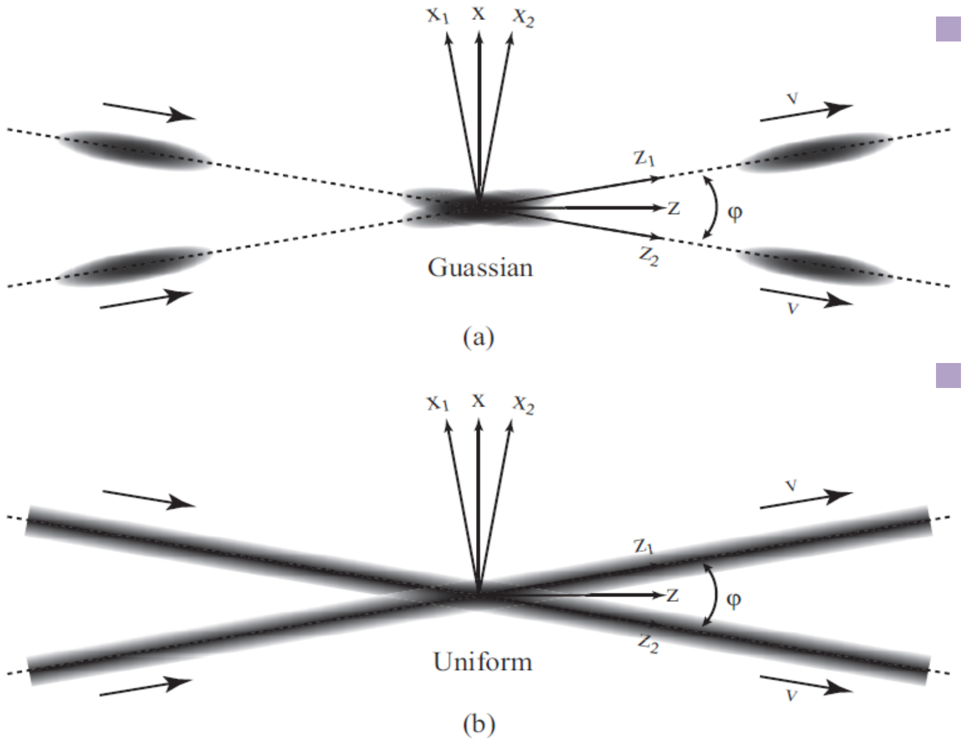
Ion-ion merging Interaction region design

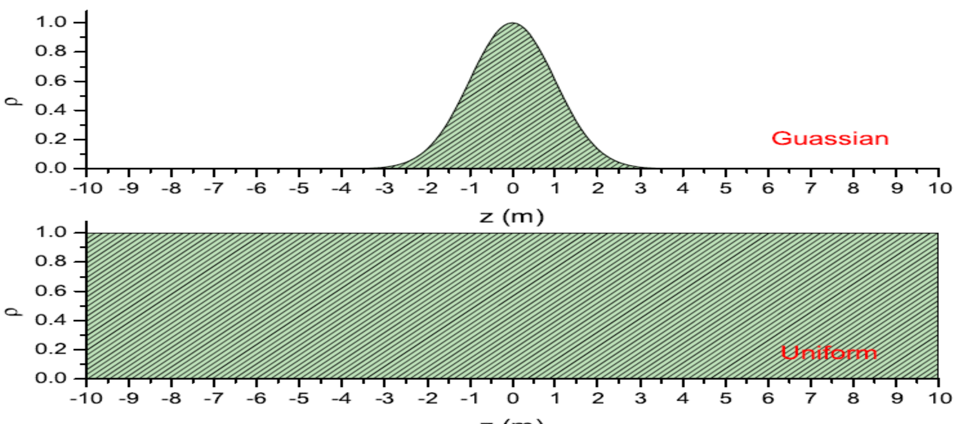






Ion-ion merging costing beam





- **Traditional colliders use bunched beam**
  - Beam energy is much higher. Space charge effect is not important. Luminosity is limited by intensity, because the total particle cannot increase further. Bunched beam contributes to higher particle density and luminosity.
  - Avoid parasitic collision
- **Ion-ion merging**
  - Peak density in longitudinal direction is limited by space charge effect. Direct Laslett tune shift should be smaller than -0.1.
  - Coasting beam scheme is equivalent to collision with the maximum density at all time.

$$L = \frac{N^2 v}{2\sqrt{\pi}\gamma\sigma_y C^2} H$$

N is limited by SC, i.e. transverse emittance and energy, independent of circumference.

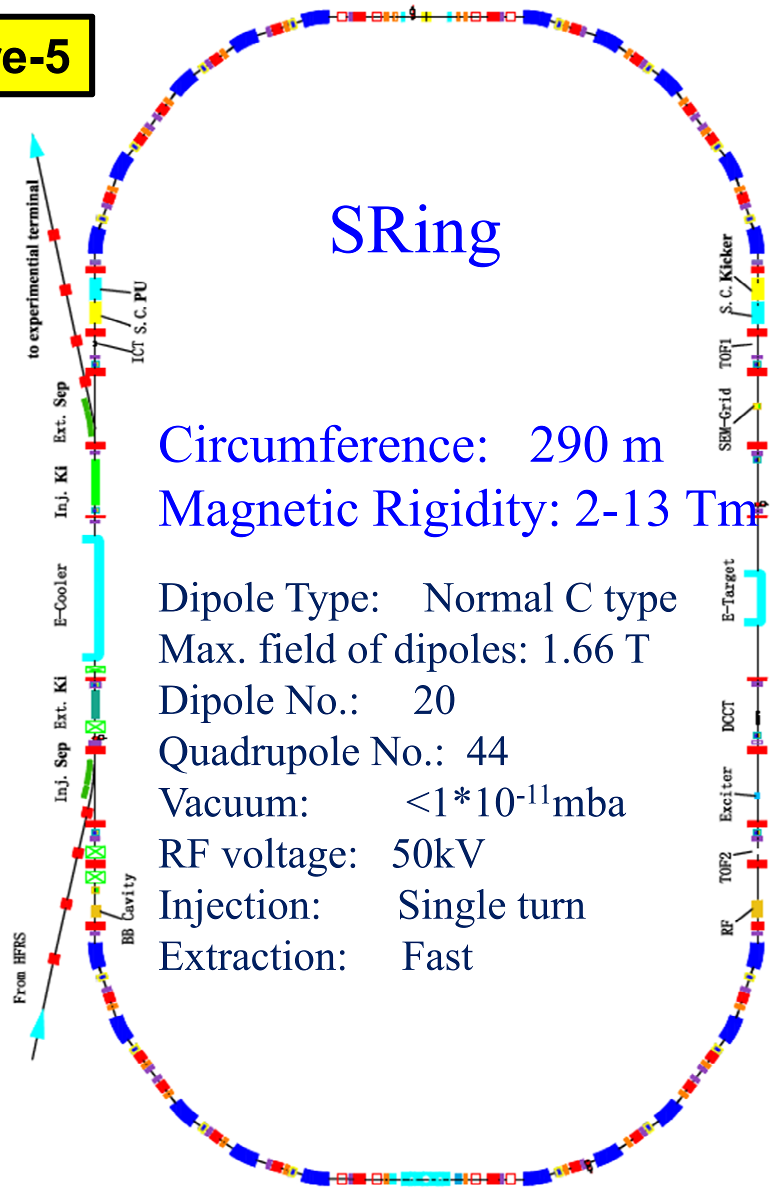
The larger circumference, the higher longitudinal particle density, the lower luminosity.

Ion-ion Merging beam parameters

Parameter	Value
Ion	$^{238}U^{92+}$
Energy(MeV/u)	637(800)
Circumference(m)	483.8
Frequency(MHz)	0.50(0.52)
Crossing angle(∘)	6.8
CM energy(MeV/u)	6(8)
Particle number	8×10^{10}
$\varepsilon_{x,rms}/\varepsilon_{y,rms}$ (π mm mrad)	1/1
β^*_x/β^*_y(m)	1/0.03
$\sigma_{x,rms}/\sigma_{y,rms}$ (mm)	1/0.173
Laslett tune shift	-0.1(-0.077)
Hourglass factor	0.9
Luminosity($cm^{-2}s^{-1}$)	**5×10^{23}**

Multi-function storage ring

Feature-5



SRing

Circumference: 290 m
Magnetic Rigidity: 2-13 Tm

Dipole Type: Normal C type
Max. field of dipoles: 1.66 T
Dipole No.: 20
Quadrupole No.: 44
Vacuum: $<1*10^{-11}$mba
RF voltage: 50kV
Injection: Single turn
Extraction: Fast

Key devices
- Electron cooling
- Stochastic cooling
- Laser cooling
- Two TOF detectors

RF operations
- Bunch Rotation
- Deceleration
- Barrier bucket stacking

Operation modes
- Isochronous mode
- Normal Mode
- Internal-target Mode
- Ion-ion merging Mode

Experiment programs
- Gas-jet target experiments
- DR experiments
- IMS & SMS
- Ion-ion merging experiments

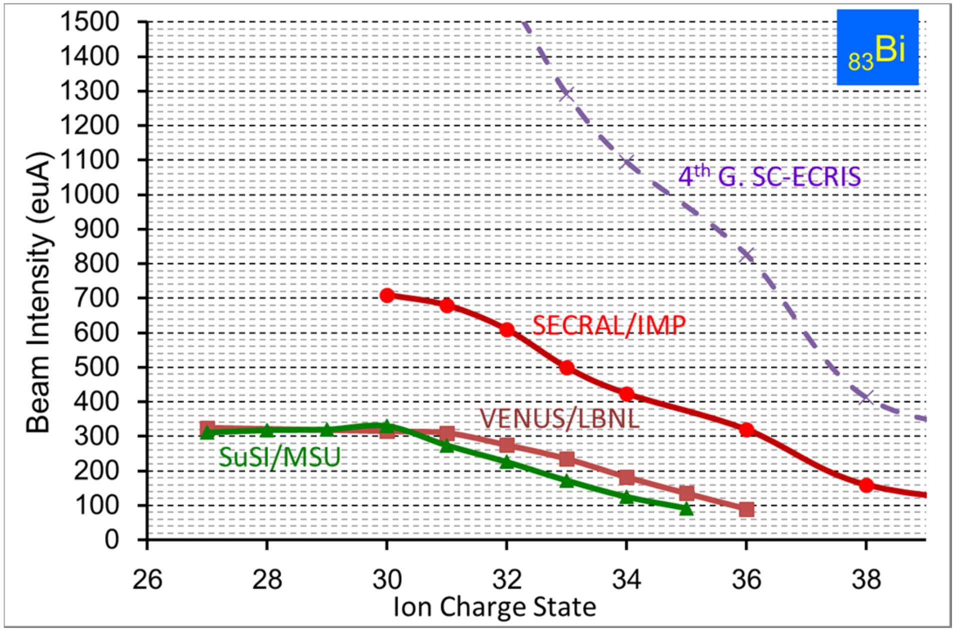
Technical Challenges and key technology R&D

- Superconducting ECR ion source
- Superconducting ion Linac
- Dynamic vacuum system
- Thin wall vacuum chamber-0.3mm

R&D No.1 Superconducting ECRIS

None of existing highly charged ion sources can meet HIAF requirements for the moment

Ion	Bi^{30+}	U^{34+}
HIAF pulsed Beam Intensity (euA)	1500 (50 pμA)	1700(50 pμA)
World Record CW Intensity (euA)	710 (<24pμA)	400(<12pμA)
3rd Generation ECRIS	SECRAL/24 GHz	VENUS/28 GHz



Intense heavy ion beam production

SECRAL High Intensity Beams

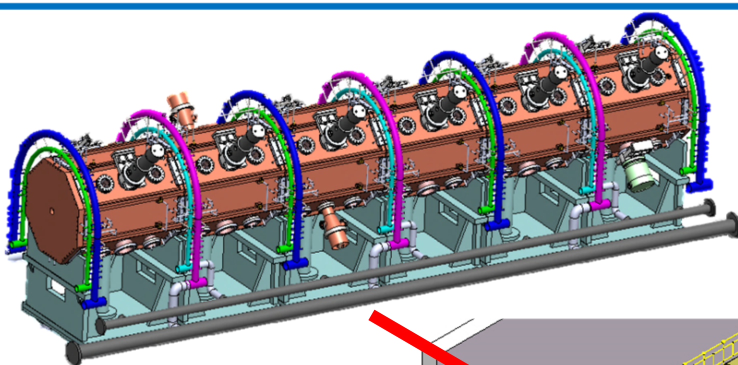
The world best performance ECRIS

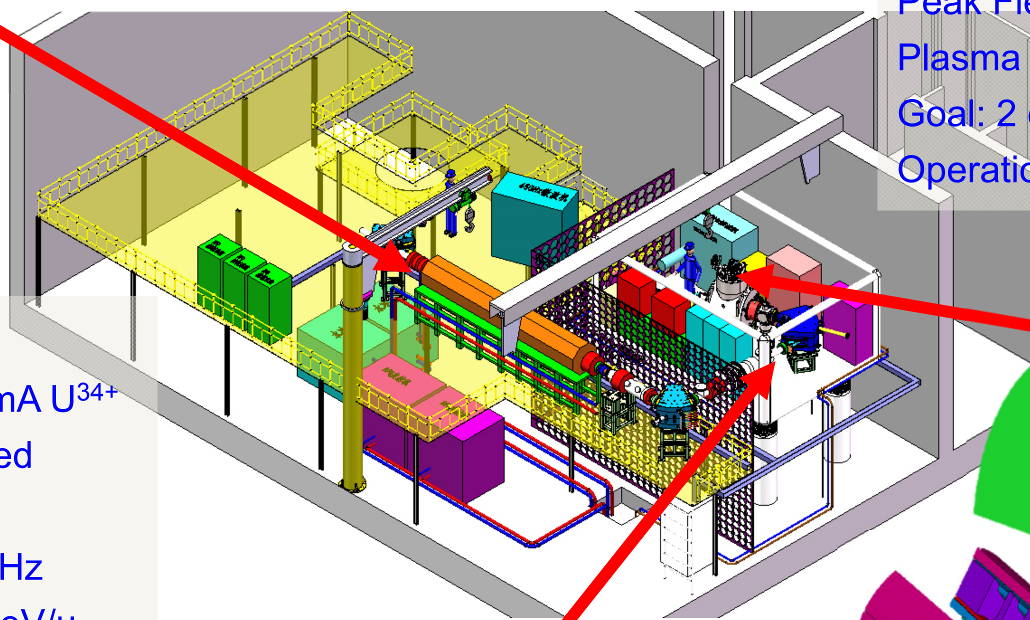
SECRAL beam intensities

Ion Beam	SECRAL (eμA)
$^{16}O^{6+}$	5000
$^{40}Ar^{11+}$	1620
$^{40}Ar^{16+}$	350
$^{40}Ca^{11+}$	710
$^{40}Ca^{14+}$	270
Xe^{26+}	1100
Xe^{30+}	320
Xe^{42+}	10
$^{209}Bi^{31+}$	680
$^{209}Bi^{41+}$	100
$^{209}Bi^{50+}$	10
$^{238}U^{33+}$	202

The world record beam intensities

LBNL VENUS
400 eμA





4^{th} G. ECRIS

ω_{rf}: 45 GHz

P_{rf}: 20 kW

Superconductor: Nb_3Sn

Peak Field: 11 T

Plasma chamber: Ø150 mm

Goal: 2 emA U^{34+}

Operation: CW/pulsed

RFQ

Beam Intensity: 2 emA U^{34+}

Operation: CW/pulsed

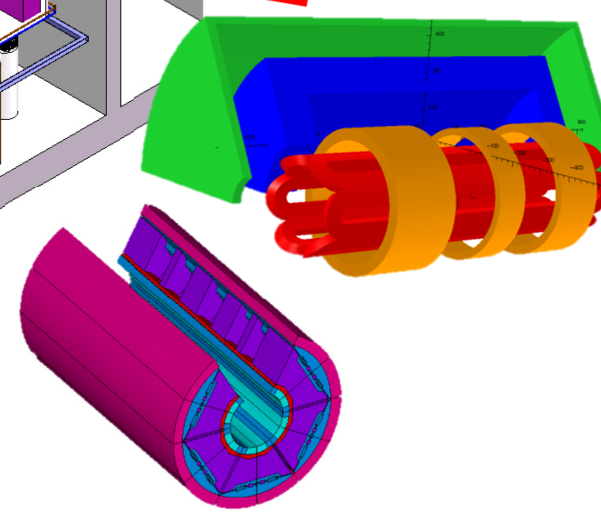
Structure: 4-vane

Frequency: 81.25 MHz

Input Energy: 14.0 keV/u

Output Energy: 0.5 keV/u

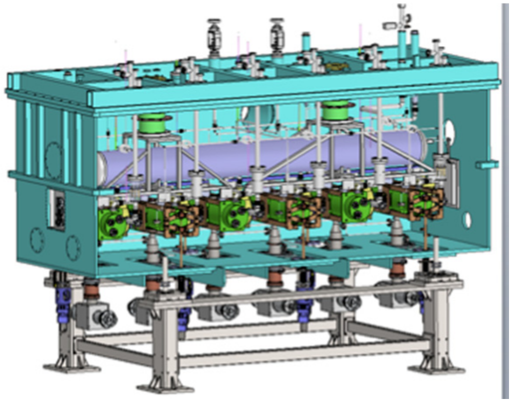
Vane Voltage: 70 kV

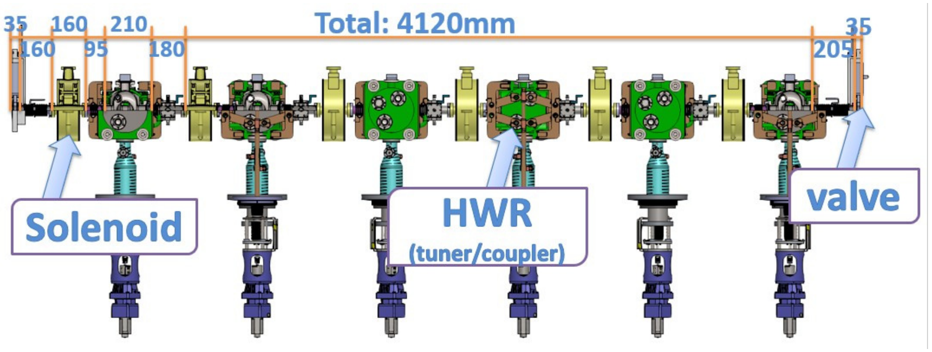


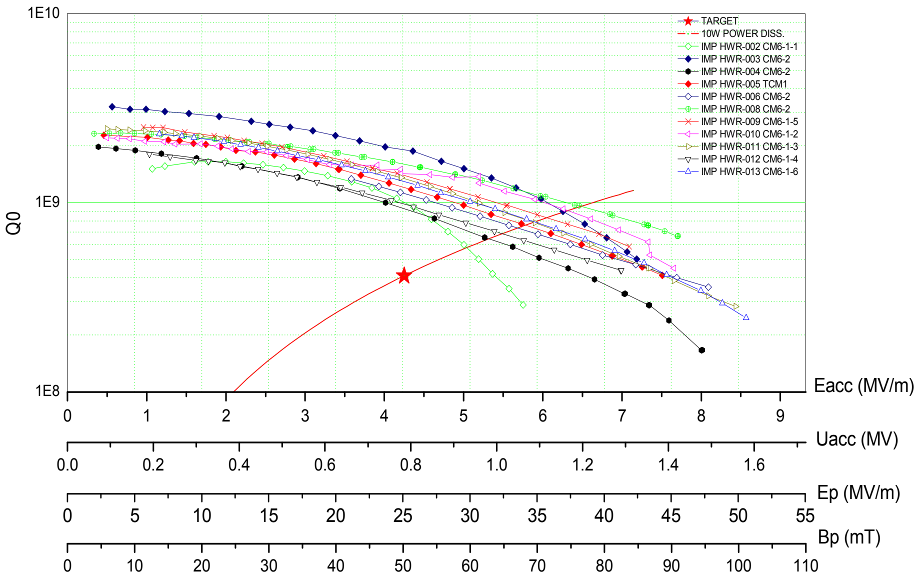
2 emA U^{34+} LEBT

R&D No.2 HWR010 cavity and cryomodule

HWR010 cavity and cryomodule were developed for Chnia ADS project.
HIAF-iLinac may use the same HWR cavity with β=0.10 and the same cryomodule.

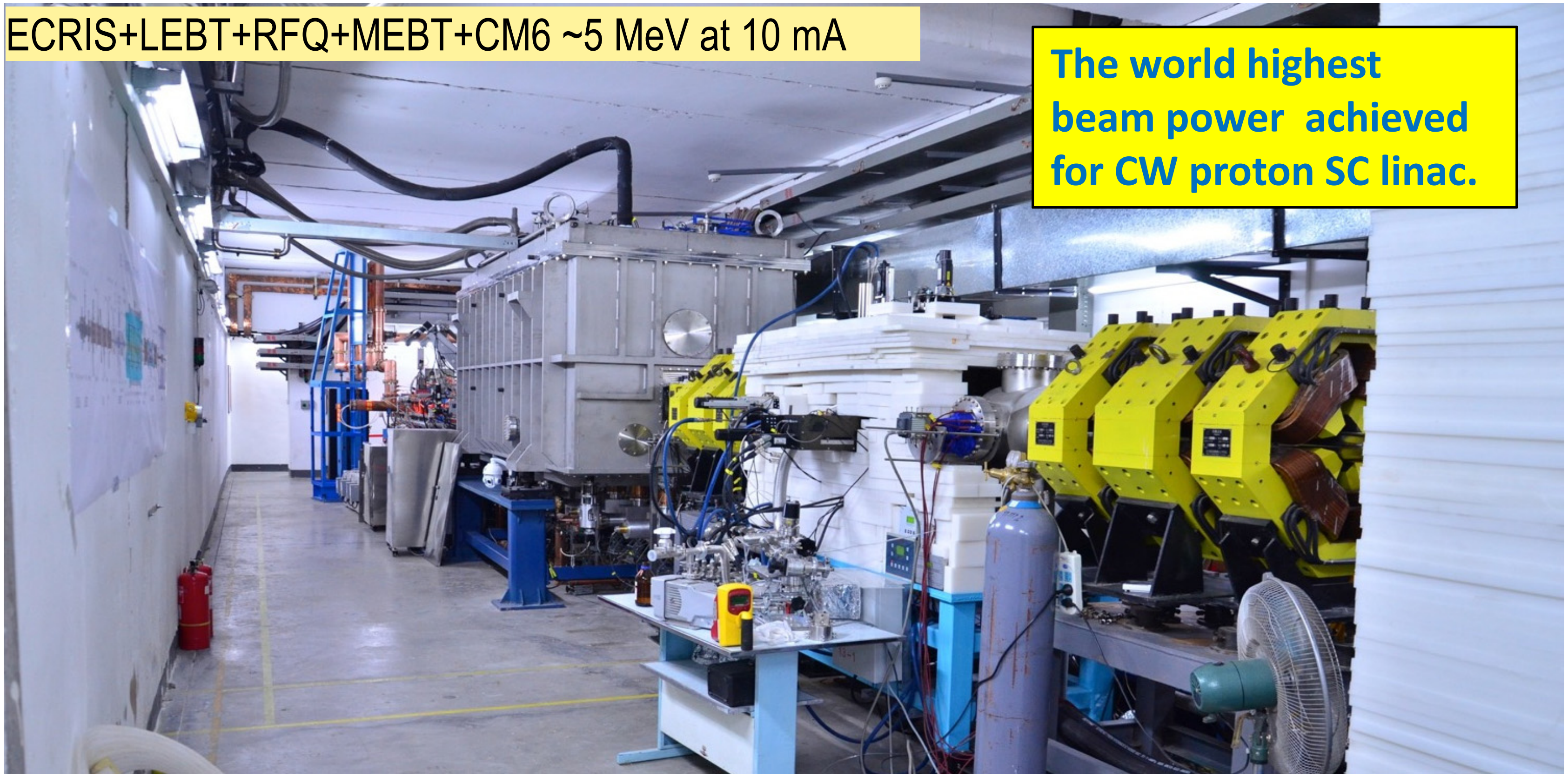






Average: $Q_0=4\times10^8$
Ep=45MV/m,Bp=90mT

Proton Beam Commissioning of 5 MeV SC section



- **June 6th, 2015, pulse beam 99us@1Hz, 5.2MeV, 10.2mA**
- **June 24th, 2015, 5.3MeV/2.7mA/CW/14kW**
- **Nov.28th, 2015, 4.6MeV/4mA CW /40 min.**
- **Jan.2nd , 2016, 4MeV/1.7 mA CW/7.5 hours**

High efficiency of Dynamic vacuum issue

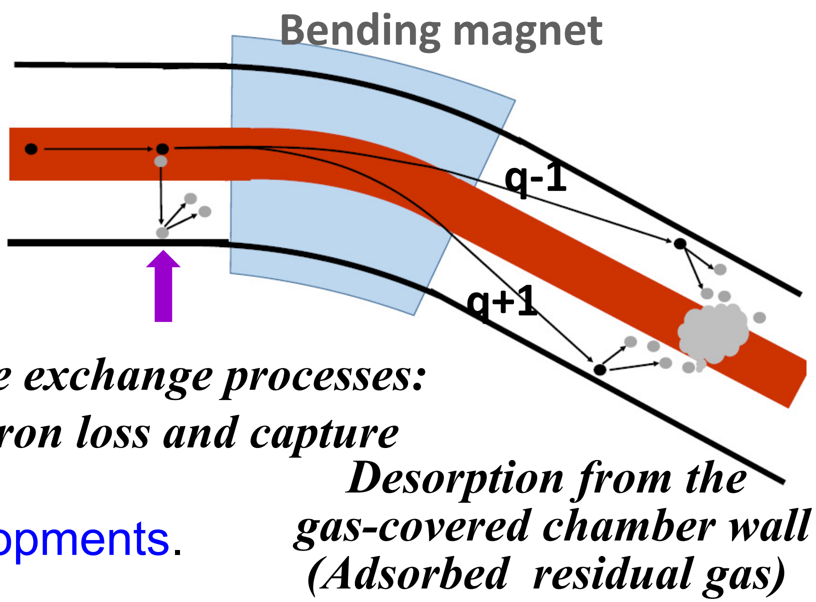
R&D No.3

To maintain extra-low and stable vacuum pressure

Beam loss mechanism:
Charge exchange of intermediate charge state ions ($^{238}U^{34+}$) **due to collision**

$$U^{34+} + X^{n+} \rightarrow U^{35+} + X \quad \text{Stripping}$$

$$U^{34+} + X^{n+} \rightarrow U^{33+} + X \quad \text{Capture}$$



CERN and GSI have done a lot of developments.

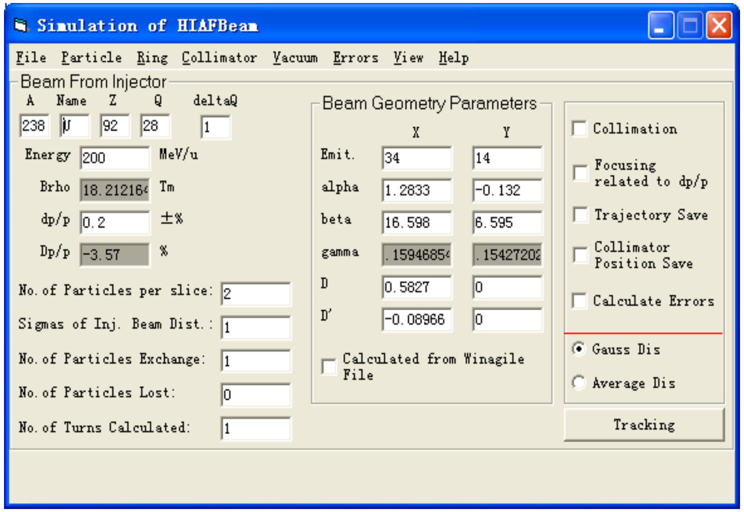
Lost ions drive a pressure bump and self amplification effect which can develop a further beam loss.

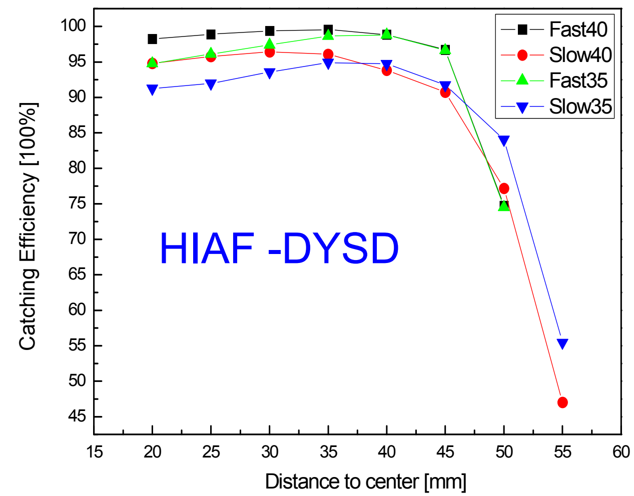
Challenges:

- How to get a high collimation efficiency of BRing? Near to 100%
- How to optimize the lattice for different type of particles?
- How to design the collimation system ?

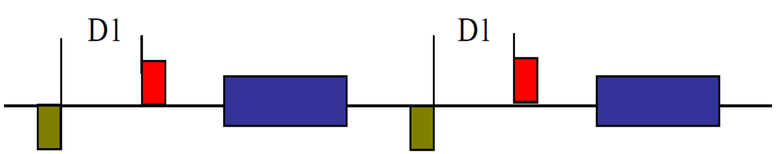
Dynamic vacuum simulation

- **A dedicated dynamic vacuum simulation code-HIAF-DYSD has been developed for optimization of dynamics design.**

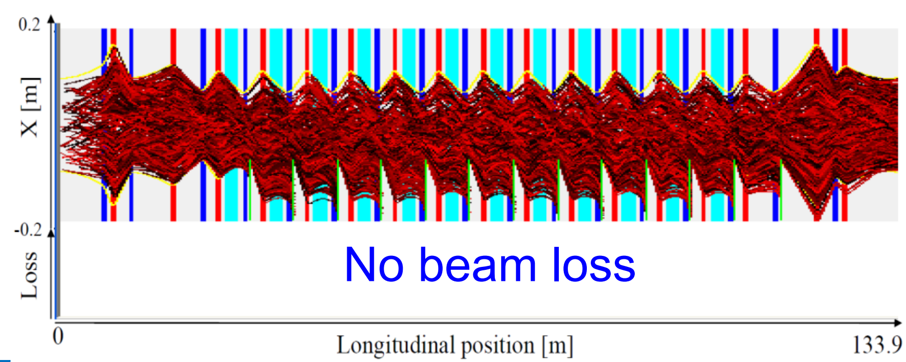




- **New Lattice has been optimized to get high collimation efficiency, the collimation efficiency is still high in the case the scraper is 20mm from the beam edge.**



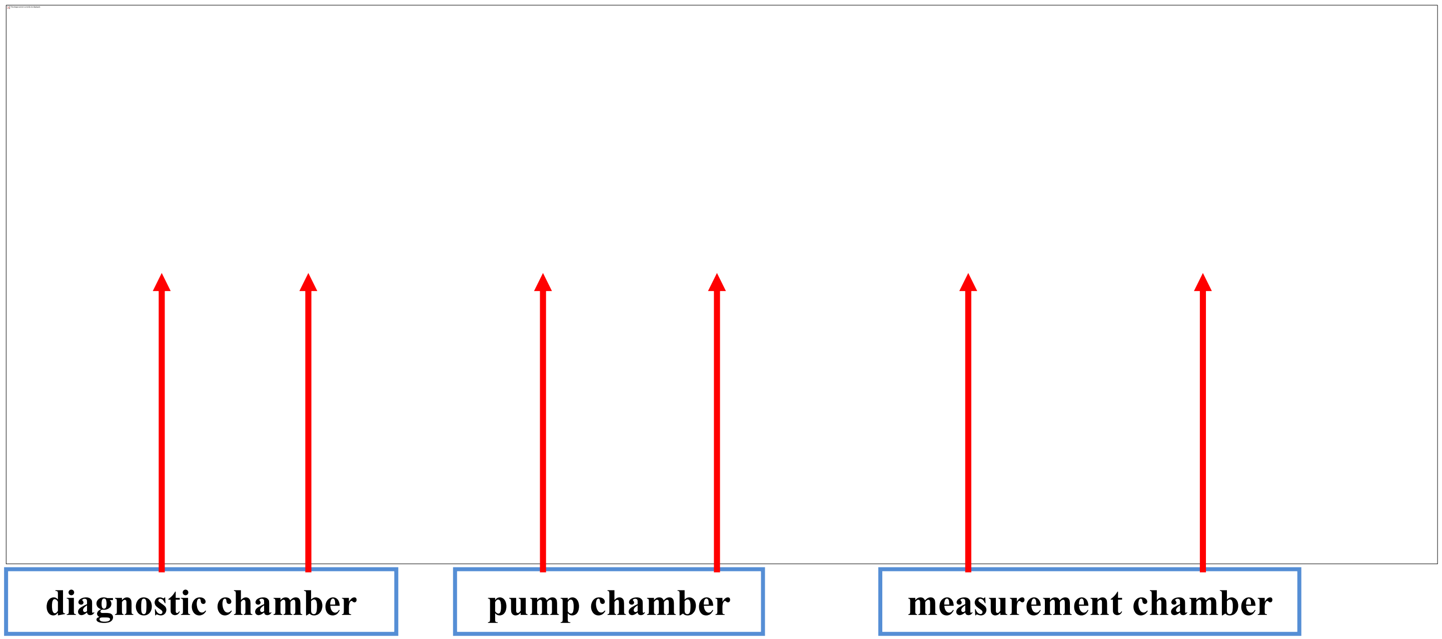
The new DF cell design



No beam loss

Dynamic vacuum system

Test platform for desorption measurement was set up. Poster: MOPR008



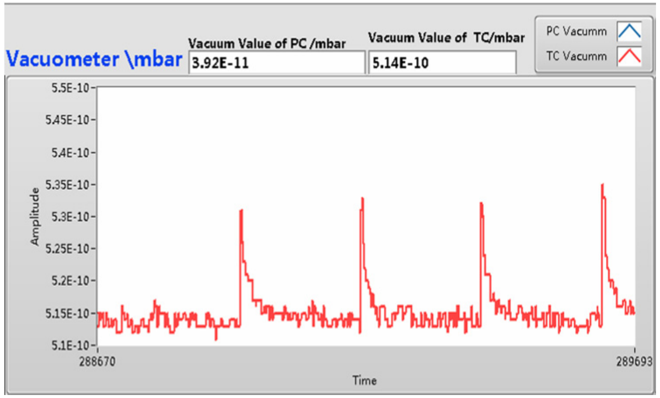
First Beam Test:

Beam: Sn^{26+},

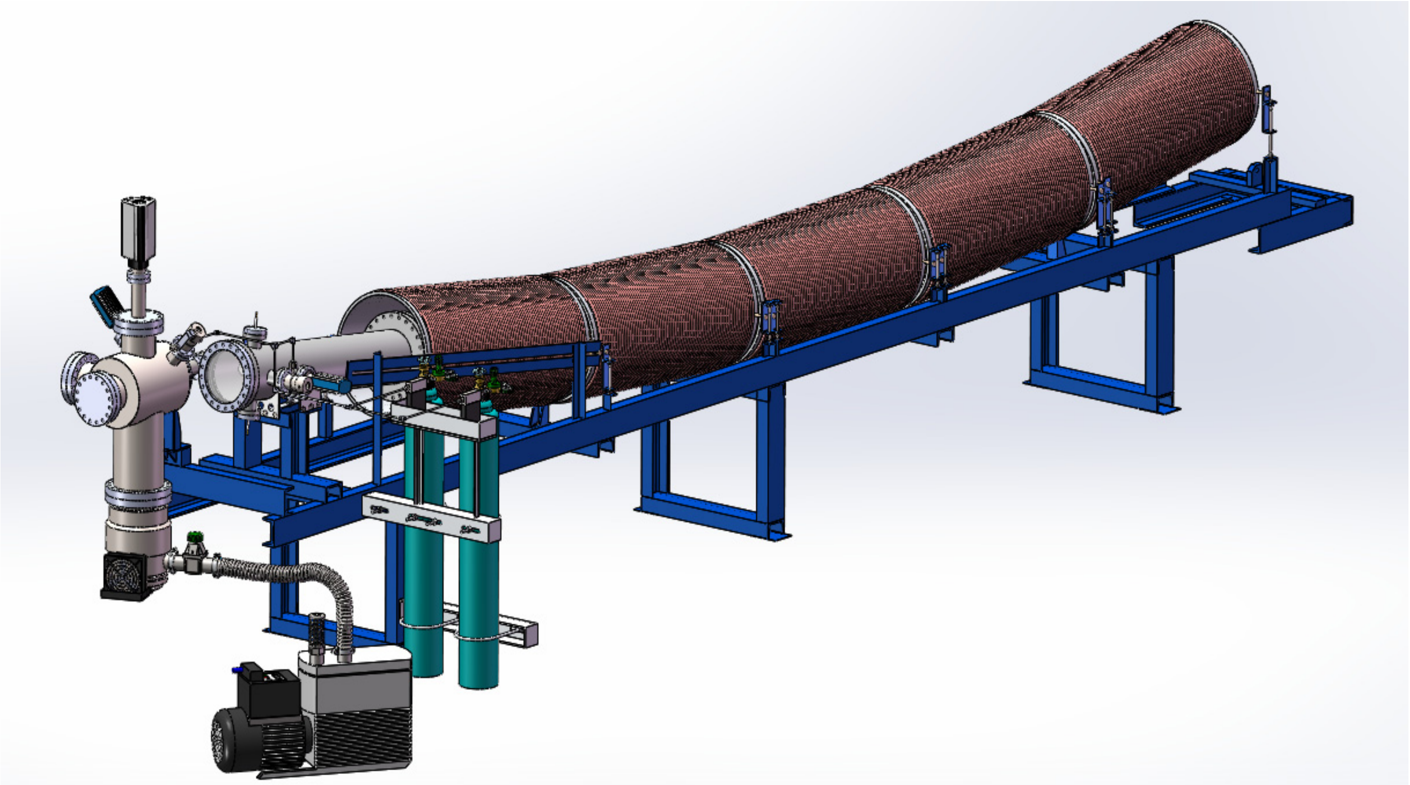
Injection Energy=3.7 MeV/u,

Extraction Energy=150 MeV/u.

DCCT: 80 uA (2*10E7)



NEG coating system



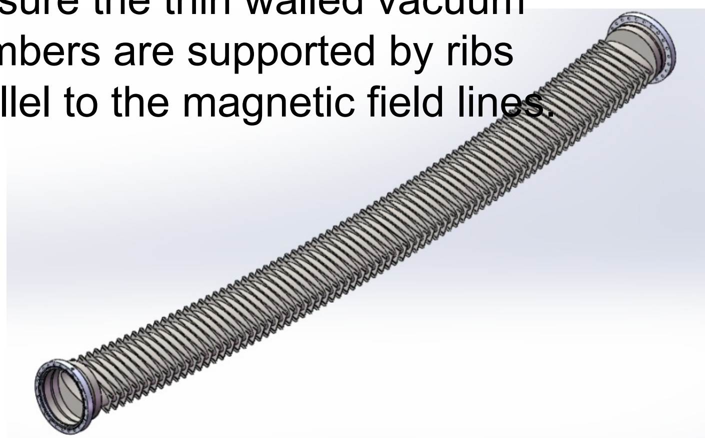
NEG dipole chamber coating facility (technology developed by CERN and GSI)

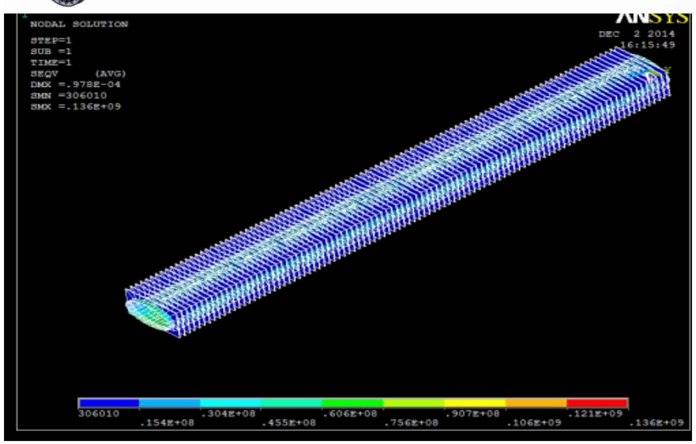
Non-Evaporable Getter thin films (NEG) is an excellent solution for conductance limited chambers, for stabilization of the dynamic vacuum pressure. For this purpose, three is a proposal to develop the chamber coating facility. A dipole chamber coating facility has been designed for HIAF.

Thin wall vacuum chamber prototype

Due to high ramping rates, thin wall vacuum chambers are needed for all magnets to keep eddy currents at a tolerable level.

To withstand the atmospheric pressure the thin walled vacuum chambers are supported by ribs parallel to the magnetic field lines.



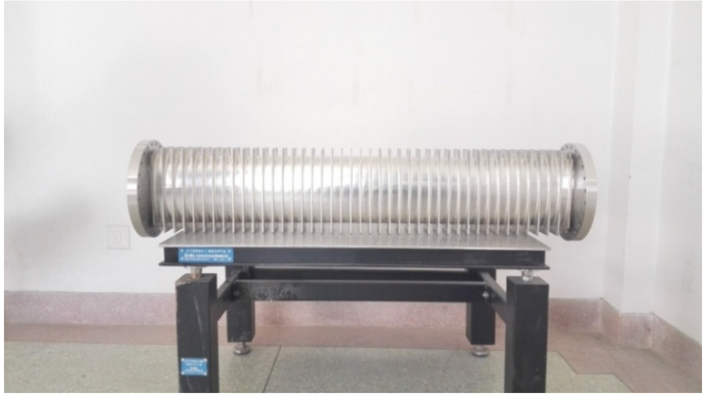


0.3 mm vacuum chamber design

0.3 mm，0.5m vacuum chamber prototype

- Elliptical aperture
- Stainless steel
- Ribs supporter parallel to the magnetic field lines

Thin wall vacuum chamber prototype



L=1.2m, 0.3mm prototype

A full size prototype is under development

(2.8m, 0.3mm, curved thin wall chamber)

Others technical challenges

- **Power supply of Bring dipole: Fast ramping rate 12T/s**
- **Two-plane painting injection tilted septum**
- **Non-interceptive beam diagnostics for high intensity beam**

…….

Summary

- HIAF will be one of the leading heavy ion accelerator facilities worldwide for nuclear physics and related researches with unique features.
- HIAF concept design has been completed and provides a basis for performance evaluation, detailed cost estimation, and technical risk assessment.
- Currently HIAF design and studies mainly focuses on beam dynamics optimization and key technology R&D. we expect to freeze the baseline of HIAF technical design in the end of this year.
- A lot of technical challenges for HIAF. Prototypes of key technologies or components were built .

Thanks for your attention!